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Public Roads

A JOURNAL OF HIGHWAY RESEARCH

A median divider and grade-separated interchange greatly facilitate traffic on U.S. 50 at Seven Corners, Alexandria, Va. (before and after photographs)

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Public Roads

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IN THIS ISSUE

U.S. DEPARTMENT OF COMMERCE
LUTHER H. HODGES, Secretary

BUREAU OF PUBLIC ROADS
REX M. WHITTON, Administrator

A New Base for The Highway Construction Bid Price Index Compiled by the Bureau of Public Roads

BY THE CONSTRUCTION AND MAINTENANCE DIVISION
BUREAU OF PUBLIC ROADS

Reported by EDWIN L. STERN, Head,
Construction Costs and Price Trends Section

For almost 30 years the Bureau of Public Roads highway construction bid price index has been a widely accepted and frequently used measure of trends in the cost of highway construction. The index, computed from information on some 30 major bid items taken from awards of contracts for Federal-aid projects, has been published quarterly since 1933. Based on the 1925–29 period, it had been extended back as far as 1922.

Many changes have occurred in the nature of highway construction since the pattern for computing the index was first developed: quantities per mile differ radically; geographic distribution of work included in the base period was much different than it is now; and bituminous pavement was not directly included in the index.

In order to overcome such deficiencies, a new construction bid price index has now been devised, using 1957–59 as a base. Surfacing will now be represented by both portland cement concrete and bituminous concrete as indicators, and nationwide total quantities will be used in lieu of per-mile quantities for the base period.

The new index will be used exclusively beginning with the report for the first quarter of 1962 and, to provide transition in use, both the new and old indexes will be included in the reports for the third and fourth quarters of 1961. The design of the new index is explained in this article, and the historical trends from 1922 are shown on the new 1957–59 base.

Introduction

IN HIGHWAY CONSTRUCTION, as in many other undertakings, the need for future planning is readily apparent; and planning for the future can best be accomplished if highway engineers and economists have a thorough knowledge of what has taken place in the past. In order that physical volumes of work required for needed highway improvements may be expressed in terms of dollars required to purchase that work, high-level planning for future highway construction requires a knowledge of the amount of highway improvement that can be purchased by any given appropriation, at current prices. This, in turn, requires a knowledge of the changes and trends in average bid prices of highway construction items over past years.

To provide definite information as to price movements and trends in highway construction, the Bureau of Public Roads computes and publishes a continuing record of quarterly variations in contract bid prices on Federal-aid highway construction. This price trend record extends back to 1922, when highway construction in the United States had reached sufficient nationwide volume and had become sufficiently standardized to provide a fairly reliable basis for the comparison of unit construction costs and progressive price movements.

The basic data for the index, compiled in the Bureau of Public Roads field offices, are obtained from the awards of contracts for Federal-aid highway projects by the State highway departments, and consist of quantities, contract unit prices, and costs for approximately 30 major bid items. These data are reported to the Public Roads Washington Office for analysis, compilation, and summarization on a nationwide basis. The resultant index has been published quarterly since 1933 as *Price Trends for Federal-aid Highway Construction* (often referred to as the "composite mile index"), and has been widely recognized in the highway construction field as a standard measure of changes and indicator of trends in highway construction bid prices.

Basis of 1925–29 Index

The details of the design of the present price index are described in an article, *An Index of the Cost of Highway Construction*, published in July 1933 in PUBLIC ROADS (vol. 14, No. 5). Briefly stated, this fixed-base type index was designed to show what it would cost, at any given time, to contract for the Federal-aid construction put in place during the 1925–29 base period. Strictly speaking, a composite highway price index should be a weighted composite of over 100 items, but the computation of such an index would involve an extremely large amount of work. Fortunately, the nature of highway construction is such that changes in prices of certain principal work items are generally accompanied by similar changes in prices of associated items or classes of work.

For example, in preparing the index on the 1925–29 base, it was assumed, with reason, that if the unit price of common excavation increased 5 percent during a quarterly period, the prices of all other types of excavation also increased approximately 5 percent during the same period. Likewise, it was assumed that percentage changes in prices of all high-type surfacing would be similar to percentage changes in portland cement concrete pavement

prices. For this reason, common excavation and concrete pavement were used as indicator items for grading and surfacing, respectively. For structures, three indicator items were used—reinforcing steel, structural steel, and structural concrete.

The relative weights for the index items were determined from expenditures for the various construction items during the base period by grouping together those items represented by each indicator item. For example, all expenditures for excavation and low-type bases were combined, and the equivalent quantity of common excavation that could be contracted for by this expenditure was derived by dividing the combined expenditure by the base-period weighted average price per cubic yard of common excavation. This latter figure, the weighted average price for common excavation, was computed by dividing the total contract quantity of common excavation in all of the States for the years 1925–29 into the total contract dollar amount for this excavation.

Similarly, the equivalent area of portland cement concrete paving was derived by dividing the sum of all money spent for high-type surfacing by the base-period weighted average price per square yard for concrete paving. No such conversion was necessary for structures, since the costs for the three index items—reinforcing steel, structural steel, and structural concrete—constituted the bulk of structure costs.

The five base-period quantities—for excavation, paving, reinforcing steel, structural steel, and structural concrete—thus obtained were each reduced to a relative quantity-per-mile basis by dividing each by the total mileage of construction during the base period. (This total mileage represented construction of various kinds, of course.) The composite index of highway construction cost for any subsequent period could then be computed by (1) multiplying these base-period per-mile quantities for the five items by the applicable current average unit price for each item, (2) dividing the sum of these products by the sum of the products of the base-period per-mile quantities and the base-period average unit prices, and (3) multiplying the quotient by 100.

This highway construction bid price index is known as a fixed-base index. It provides a means for determining what it would cost to contract for the base-period quantities at the current prices of any particular period. In other words, the cost of the base-period quantities at prices of a particular period are compared with the cost of the base-period quantities at the base-period prices.

The reliability of the trends in the fixed-base index has been checked periodically by the computation of a changing-base index, in which the quantities for the particular period are used instead of the quantities for the 1925–29 base period. In addition, as a further check, the changing-base index computations employ the quantities for all major highway construction bid items, in lieu of the quantities for only the five indicator items. This changing-base index provides a means for determining how much more or less it would cost to contract for particular-period quantities at particular-period prices than it would cost to contract for the same quantities at base-period prices. It has been found that, over a period of years, the trends developed by the fixed-base method produce considerably smoother curves than the changing-base method. This better stability of the fixed-base index indicates its greater reliability for use in the prediction of future price trends.

Deficiencies in the 1925–29 Index

Many changes have occurred in the nature of highway construction during the three decades since the fixed-base index was first developed. As a consequence, certain deficiencies have become apparent in recent years, as described in the following paragraphs.

Table 1.—Variation of percentage values of price index indicator items with use of 1925–29 and 1957–59 base data

Item	1925–29 quantities at 1925–29 prices	1925–29 quantities at 1957–59 prices	1957–59 quantities at 1957–59 prices
	Percent	*Percent*	*Percent*
Excavation	36	24	34
Surfacing:			
Portland cement concrete	48	54	15
Bituminous concrete	0	0	16
Subtotal, surfaces	48	54	31
Structures:			
Reinforcing steel	5	7	6
Structural steel	2	3	11
Structural concrete	9	12	18
Subtotal, structures	16	22	35
Total	100	100	100

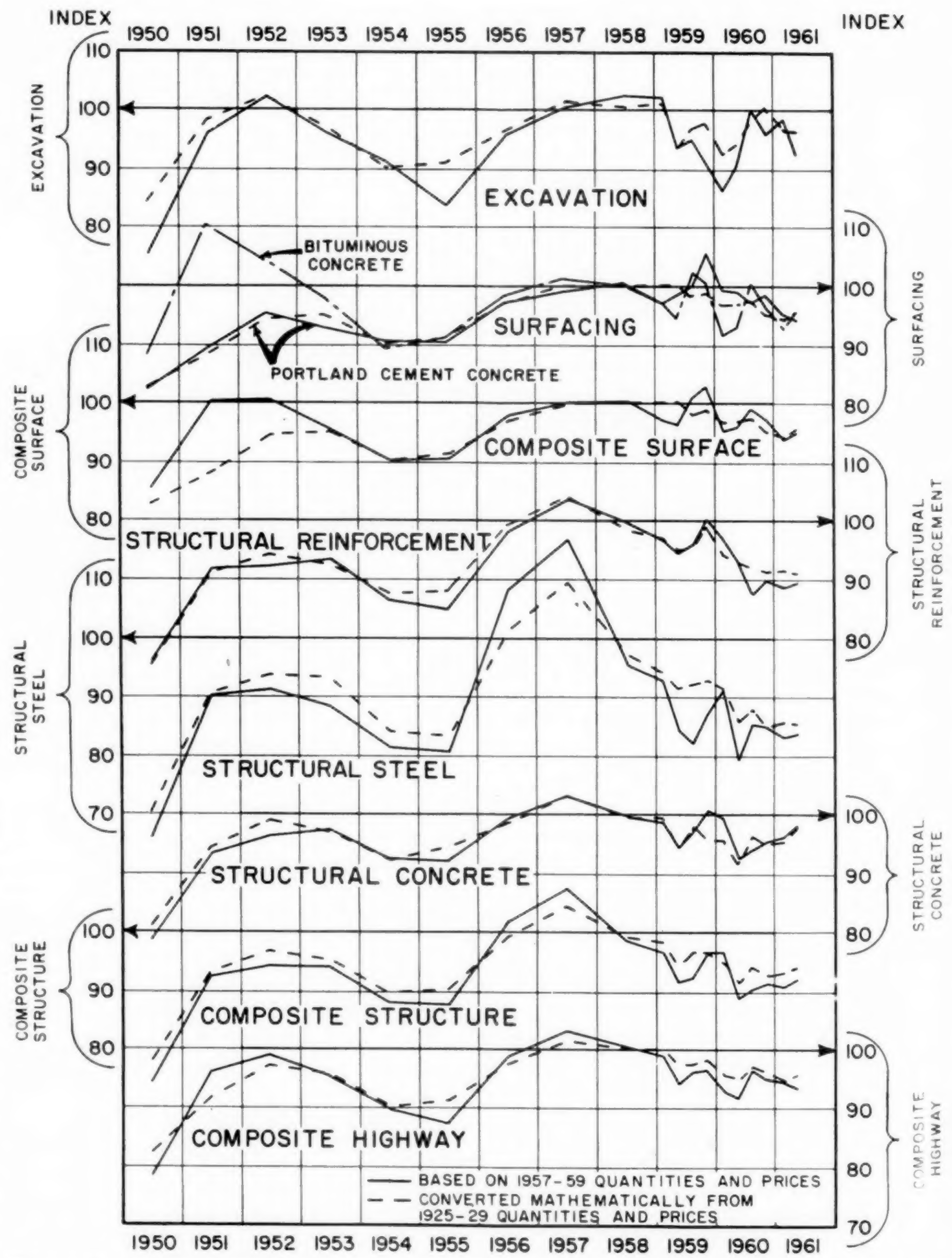

Figure 1.—Comparison of trends of the original and new bid price indexes, 1950 to date.

Quantities.—The 1925–29 base period is quite remote and the base-period per-mile quantities are no longer representative of present Federal-aid highway work. While it is true that the magnitudes of the base quantities do not affect the computed index values so long as their magnitudes relative to each other do not change, there has been a considerable change in the relative weights of grading, surfacing, and structures from those of the base period. Table 1 shows a comparison of the percentage values for the indicator items as computed for the 1925–29 quantities at 1925–29 prices and at 1957–59 prices and for 1957–59 quantities at 1957–59 prices. Although the actual quantity of surfacing put in place during the 1957–59 period was much greater than that put in place during the 1925–29 period, percentagewise surfacing decreased considerably in relation to grading and structures. This results principally because of the higher level of geometric standards adopted for highway construction during the past two decades, requiring proportionally more earthwork and structures.

Geographic distribution.—The geographic distribution of the work during the base period 1925–29 was quite different from 1957–59 or present-day periods. This has an appreciable effect, since quantities and bid prices vary considerably across the country.

Bituminous pavements.—The continued calculation of the composite mile index without direct consideration of the costs of bituminous pavements created some doubt as to its accuracy, especially in view of the heavy relative weight of surfacing in the composite index. As previously stated, the basic assumption in the original design of the index was that prices for portland cement concrete pavement would accurately reflect the price movements for all types of pavements. This was probably valid at the time. It has been determined that there is some similarity in the price trends of portland cement concrete pavement and bituminous concrete pavement (the bituminous type chosen as an indicator for the redesigned index). However, a difference of several percent in the index results when the actual average prices for each type are separately derived.

Index Redesigned

In order to overcome these deficiencies, the original fixed-base index has now been redesigned. The new index will employ the 3-year period 1957–59 as a base, in accordance with the general endeavor of the Federal Government, under the leadership of the Bureau of the Budget, to establish all indexes published by Federal agencies on the uniform 1957–59 base period, beginning January 1, 1962. The method of computation for the new 1957–59 base index is similar to that used for the 1925–29 base index except that sur-

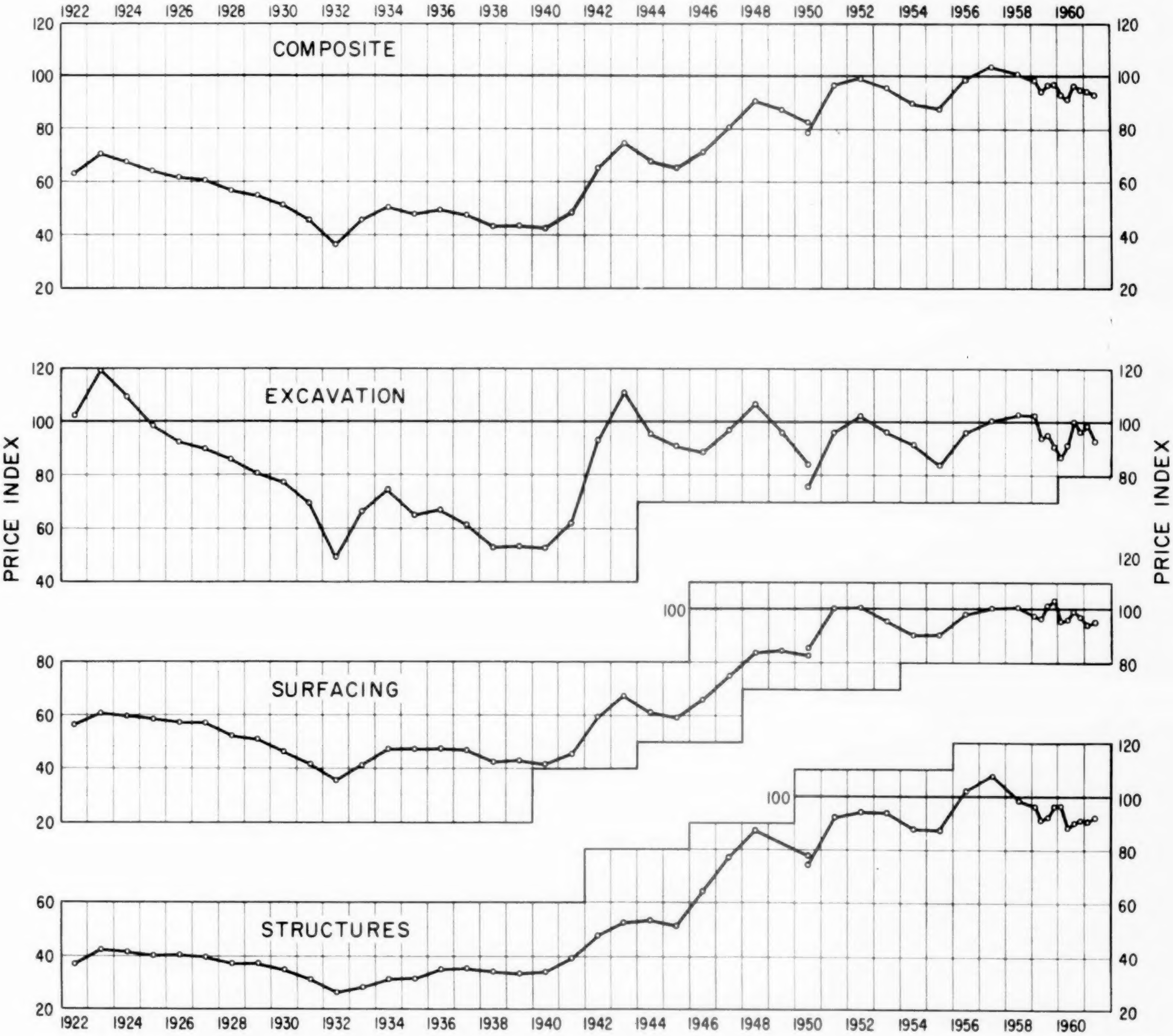

Figure 2.—Trends of the new bid price indexes, 1922 to date. (See explanation in text.)

facing will be represented by two indicator items, portland cement concrete and bituminous concrete. In addition, nationwide total quantities will be used in lieu of per-mile quantities for the base period. The method for computing the 1957–59 total base quantities of the five original items is the same as described for the 1925–29 total base quantities. The 1957–59 bituminous concrete surfacing base quantity, in tons, was computed by dividing the 1957–59 United States average unit price per ton for bituminous concrete surfacing into the total 1957–59 contract cost for all types of bituminous surfacing.

Figure 1 shows comparisons, from 1950 to date, of the trends of the original index, based on 1925–29 quantities but converted mathematically to a 1957–59 base = 100, and the trends of the new index based on 1957–59 quantities. (The trend of bituminous surfacing prices is shown only for 1957–59 quantities, since this element was not included in the 1925–29 base index.) The variations are significant in some periods.

Table 2 shows the 1957–59 base quantities, average unit prices, total dollar amounts, and relative weights of the index items. As already shown in table 1, the relative weights in the new index vary considerably from those in the old index.

Table 2.—Basic values and relative weights of the 1957-59 base index

Item	Unit	Base quantity	Base unit price	Base dollar amount	Relative weight
		Thousands		*Thousands*	*Percent*
Excavation	cu. yd	3, 641, 885	$0. 42	$1, 529, 592	33. 8
Surfacing:					
Portland cement concrete	sq. yd	154, 953	4. 38	678, 221	15. 0
Bituminous concrete	ton	111, 516	6. 66	742, 472	16. 4
Subtotal, surfaces				1, 420, 693	31. 4
Structures:					
Reinforcing steel	lb	2, 206, 879	. 129	285, 139	6. 3
Structural steel	lb	2, 581, 462	. 195	502, 294	11. 1
Structural concrete	cu. yd	14, 583	54. 18	790, 027	17. 4
Subtotal, structures				1, 577, 460	34. 8
Total				4, 527, 745	100. 0

In developing the 1957–59 based index for any given period, the index for each item is computed by dividing the base-period unit price into the United States average unit price for the particular period, and multiplying the quotient by 100. The composite surfacing index is computed by multiplying the average unit prices of the given period for portland cement concrete surfacing and bituminous concrete surfacing by their respective base quantities, dividing the sum of these products by the total base-period amount ($1,420,693,000, from table 2) for the two items, and multiplying the quotient by 100. The composite structure index, and the composite highway construction cost index (for excavation, surfacing, and structures combined), are computed in a similar manner, using the appropriate prices, quantities, and dollar amounts.

Figure 2 is the graphical representation of the new index trends; table 3 (p. 199) shows the data on which the curves are based. Index figures for 1922–50 are simple mathematical conversions from the 1925–29 base to the 1957–59 base. They were derived from the previously computed figures, using 1925–29 base quantities and prices, and dividing the figures for each year by the average of the figures for the years 1957, 1958, and 1959. Revised figures for 1950 and subsequent years are computed from 1957–59 base quantities and prices. The breaks in the curves in figure 2 indicate indexes for 1950 computed by both methods. Prices for portland cement concrete surfacing reflect adjustments to base period thicknesses in each State and do not include costs for reinforcing steel and joints.

The new index, computed on the 1957–59 base, will be used beginning with the report for the first quarter of calendar year 1962. In order to facilitate the change-over, the reports of price trends for Federal-aid highway construction for the third and fourth quarters of calendar year 1961 will include index data on both the 1925–29 and 1957–59 bases.

New Publications

Landslide Investigations

The Bureau of Public Roads has recently published *Landslide Investigations*, a field handbook on landslides and related phenomena. Prepared primarily for the highway location engineer, the publication should also be of interest to other engineers, geologists, teachers, and students.

The convenient pocket-size, 67-page handbook is divided into four parts. The brief introductory section describes geologic processes, rocks and soil types, and geologic structures which provide the setting for landslides. The second section involves the recognition of phenomena presaging the advent of slide movements, and those characteristic of the landslide itself. The third is devoted to methods of landslide prevention, control, and correction. The fourth section discusses details of mapping and reporting landslides. A glossary of terms is also included.

The 31 illustrations, with self-explanatory captions, portray both conventional techniques and some unique methods for overcoming landslide problems. The handbook, designed for field use and not intended to be an exhaustive treatise, lists five major publications on the subject of landslides.

Landslide Investigations is available from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C., at 30 cents per copy.

Design Charts for Open-Channel Flow

The Bureau of Public Roads has recently published *Design Charts for Open-Channel Flow*, making generally available a group of hydraulic charts which facilitate the computation of uniform flow in open channels. Some of the charts are also useful in the design of storm drains. The publication is not intended to be a treatise on the design of open channels, although a brief discussion of the principles of flow in open channels is included. Rather, it is intended as a working tool that should be of considerable service to the designer already familiar with the subject.

The 105-page publication contains 82 charts which provide direct solution of the Manning equation for uniform flow in open prismatic channels of various cross sections; instructions for using the charts; a table of recommended values of *n* in the Manning equation and tables of permissible velocities in earth and vegetated channels; instructions for constructing charts similar to those presented; and a nomograph for use in the solution of the Manning equation. Charts are included for rectangular, trapezoidal, and triangular channels, grass-lined channels, circular pipe channels, pipe-arch channels, and oval concrete pipe channels.

Practically all of the material in this publication has appeared previously in the processed *Highway Drainage Manual* prepared by the Public Roads Regional Office in Hagerstown, Md.

Design Charts for Open-Channel Flow, which is the third in a series on the hydraulic design of highway drainage structures published by the Bureau of Public Roads, is available from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C., at 70 cents per copy.

Table 3.—Price trends for Federal-aid highway construction, 1957–59 base [1]

Year	Common excavation: Bid price	Common excavation: Index	Surfacing: Portland cement concrete: Bid price	Surfacing: Portland cement concrete: Index	Surfacing: Bituminous concrete: Bid price	Surfacing: Bituminous concrete: Index	Surfacing index	Structures: Reinforcing steel: Bid price	Structures: Reinforcing steel: Index	Structures: Structural steel: Bid price	Structures: Structural steel: Index	Structures: Structural concrete: Bid price	Structures: Structural concrete: Index	Structures index	Composite index
INDEXES CONVERTED MATHEMATICALLY FROM 1925–29 BASE TO 1957–59 BASE [2]															
	Cu. yd.		*Sq. yd.*		*Tons*			*Lb.*		*Lb.*		*Cu. yd.*			
1922	$0.40	102.5	$2.28	56.9	------	------	56.9	$0.050	38.1	$0.074	37.3	$20.18	36.6	37.2	63.2
1923	.47	119.3	2.43	60.6	------	------	60.6	.057	43.4	.078	39.4	23.37	42.4	42.5	70.4
1924	.43	109.4	2.40	59.9	------	------	59.9	.057	43.4	.077	38.8	22.91	41.6	41.9	67.6
1925	.39	98.5	2.36	58.9	------	------	58.9	.056	42.6	.067	33.8	22.53	40.9	40.6	64.2
1926	.36	92.8	2.29	57.1	------	------	57.1	.053	40.3	.074	37.3	22.76	41.3	40.6	61.8
1927	.35	89.8	2.29	57.1	------	------	57.1	.051	38.8	.071	35.8	22.65	41.1	39.7	60.9
1928	.34	85.9	2.10	52.4	------	------	52.4	.049	37.3	.067	33.8	21.22	38.5	37.6	56.9
1929	.32	80.6	2.05	51.1	------	------	51.1	.048	36.5	.059	29.8	21.58	39.2	37.2	55.0
1930	.30	77.3	1.86	46.4	------	------	46.4	.045	34.2	.061	30.8	20.08	36.4	35.0	51.2
1931	.27	69.5	1.68	41.9	------	------	41.9	.040	30.4	.054	27.2	18.02	32.7	31.3	45.9
1932	.18	49.2	1.44	35.9	------	------	35.9	.034	25.9	.046	23.2	15.33	27.8	26.6	36.4
1933	.26	66.2	1.67	41.6	------	------	41.6	.038	28.9	.046	23.2	16.15	29.3	28.2	45.8
1934	.29	74.6	1.90	47.4	------	------	47.4	.043	32.7	.053	26.7	17.73	32.2	31.6	50.2
1935	.26	65.6	1.90	47.4	------	------	47.4	.044	33.5	.052	26.2	17.78	32.3	31.9	48.1
1936	.26	67.0	1.91	47.6	------	------	47.6	.046	35.0	.060	30.3	20.25	36.8	35.2	49.5
1937	.24	61.8	1.89	47.1	------	------	47.1	.048	36.5	.066	33.3	19.76	35.9	35.8	47.4
1938	.21	53.5	1.72	42.9	------	------	42.9	.045	34.2	.063	31.8	19.06	34.6	34.1	43.5
1939	.21	53.5	1.73	43.1	------	------	43.1	.044	33.5	.059	29.8	19.13	34.7	33.6	43.4
1940	.21	53.0	1.68	41.9	------	------	41.9	.045	34.2	.063	31.8	19.17	34.8	34.3	42.8
1941	.24	62.0	1.87	46.6	------	------	46.6	.054	41.1	.076	38.3	21.44	38.9	39.4	48.6
1942	.37	93.2	2.39	59.6	------	------	59.6	.065	49.5	.090	45.4	26.16	47.5	47.8	65.0
1943	.44	111.0	2.71	67.6	------	------	67.6	.067	51.0	.095	47.9	30.19	54.8	52.6	74.6
1944	.37	95.4	2.45	61.1	------	------	61.1	.064	48.7	.089	44.9	31.94	58.0	53.4	67.6
1945	.36	91.0	2.38	59.4	------	------	59.4	.062	47.2	.077	38.8	31.62	57.4	51.8	65.1
1946	.35	88.7	2.65	66.1	------	------	66.1	.075	57.1	.113	57.0	38.79	70.4	64.4	71.1
1947	.38	97.0	3.01	75.1	------	------	75.1	.093	70.8	.132	66.6	45.84	83.2	77.0	80.6
1948	.42	106.8	3.37	84.0	------	------	84.0	.108	82.2	.158	79.7	51.00	92.6	87.6	90.3
1949	.38	96.2	3.40	84.8	------	------	84.8	.104	79.1	.146	73.7	47.36	86.0	82.3	87.1
1950	.33	84.6	3.32	82.8	------	------	82.8	.100	76.1	.139	70.1	44.62	81.0	78.0	82.3
INDEXES COMPUTED FROM 1957–59 BASE QUANTITIES AND PRICES [3]															
1950	$0.32	75.7	$3.62	82.7	$5.89	88.5	85.7	$0.099	76.2	$0.129	66.1	$42.62	78.7	74.2	78.3
1951	.40	96.2	3.92	89.6	7.33	110.1	100.3	.119	92.0	.176	90.4	50.72	93.6	92.3	96.1
1952	.43	102.4	4.19	95.7	6.98	104.8	100.5	.119	92.4	.178	91.3	52.24	96.4	94.1	98.9
1953	.40	96.2	4.07	93.0	6.53	98.1	95.6	.121	93.8	.172	88.6	52.82	97.5	94.0	95.3
1954	.38	91.4	3.98	90.9	5.97	89.7	90.3	.112	86.7	.159	81.5	50.15	92.6	88.0	89.9
1955	.35	84.0	3.96	90.5	6.07	91.2	90.8	.110	85.2	.157	80.9	50.01	92.3	87.4	87.3
1956	.40	96.0	4.26	97.3	6.58	98.8	98.1	.127	97.9	.212	108.9	53.74	99.2	102.0	98.8
1957	.42	100.7	4.34	99.2	6.75	101.4	100.3	.134	104.0	.228	117.0	55.98	103.3	107.8	103.1
1958	.43	102.9	4.41	100.8	6.67	100.2	100.5	.129	99.9	.186	95.7	54.10	99.9	98.5	100.6
1959:															
1st quarter	.43	102.6	4.26	97.3	6.50	97.6	97.5	.125	97.1	.181	93.1	53.53	98.8	96.7	98.9
2nd quarter	.40	94.0	4.33	98.9	6.31	94.8	96.8	.123	94.9	.165	84.6	51.19	94.5	91.4	94.0
3rd quarter	.40	95.2	4.38	100.1	6.82	102.4	101.3	.124	96.3	.160	82.3	52.59	97.1	92.2	96.1
4th quarter	.38	90.7	4.64	106.0	6.70	100.6	103.2	.130	100.7	.170	87.1	54.67	100.9	96.5	96.6
Average	.40	95.7	4.40	100.5	6.58	98.8	99.6	.126	97.2	.169	86.8	53.00	97.8	94.2	96.4
1960:															
1st quarter	.37	86.9	4.36	99.6	6.11	91.8	95.5	.125	97.0	.178	91.6	53.98	99.6	96.6	93.0
2nd quarter	.38	91.2	4.35	99.4	6.20	93.1	96.1	.121	93.3	.155	79.7	50.20	92.7	88.7	91.9
3rd quarter	.42	100.2	4.27	97.6	6.71	100.8	99.2	.114	87.8	.167	85.7	50.97	94.1	90.3	96.5
4th quarter	.41	96.4	4.33	98.9	6.44	96.7	97.8	.116	90.1	.166	85.1	51.71	95.5	91.2	95.0
Average	.39	93.8	4.33	98.9	6.37	95.7	97.2	.119	92.1	.167	85.6	51.72	95.5	91.7	94.1
1961:															
1st quarter	.41	98.3	4.18	95.5	6.19	93.0	94.2	.115	89.0	.162	83.4	52.14	96.2	90.8	94.4
2nd quarter	.39	92.6	4.13	94.4	6.38	95.8	95.1	.116	89.6	.163	83.9	53.25	98.3	92.2	93.2
1957–59 base [4]	0.42	100.0	4.38	100.0	6.66	100.0	100.0	0.129	100.0	0.195	100.0	54.18	100.0	100.0	100.0
INDEXES COMPUTED ON PREVIOUS QUARTER BASE [5]															
1960:															
1st quarter	------	95.8	------	94.0	------	91.2	92.6	------	96.3	------	105.2	------	98.7	100.1	96.2
2nd quarter	------	104.9	------	99.8	------	101.5	100.6	------	96.2	------	87.0	------	93.0	91.8	98.8
3rd quarter	------	109.9	------	98.2	------	108.2	103.3	------	94.1	------	107.5	------	101.5	101.8	105.0
4th quarter	------	96.2	------	101.4	------	96.0	98.5	------	102.6	------	99.3	------	101.5	101.0	98.5
1961:															
1st quarter	------	102.0	------	96.5	------	96.1	96.3	------	98.8	------	98.0	------	100.8	99.6	99.4
2nd quarter	------	94.2	------	98.8	------	103.0	101.0	------	100.7	------	100.6	------	102.2	101.5	98.7

[1] Base for composite index, 1957–59, involves 3,641,885,000 cu. yd. of roadway excavation; 154,953,000 sq. yd. of portland cement concrete surfacing with average thickness of 9.1 in.; 111,516,000 tons of bituminous concrete surfacing; 2,206,879,000 lb. of reinforcing steel for structures; 2,581,462,000 lb. of structural steel; and 14,583,000 cu. yd. of structural concrete.
[2] Derived from the previously computed figures, using 1925–29 base quantities and prices, and dividing the figures for each year by the average of the figures for 1957, 1958, and 1959.
[3] Prices for portland cement concrete surfacing reflect adjustments to base period thicknesses in each State and do not include costs for reinforcing steel and joints.
[4] Bid prices for the base period, 1957–59, for which the index is 100.
[5] Index for each quarter as computed using an index of 100 for the preceding quarter.

Dynamic Weighing of Vehicles

by JOHN A. DEARINGER
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A dependable method of weighing the axle loads of a moving vehicle is needed in the collection of highway planning data and as an aid to the enforcement of load limit regulations. A research project now under way at the University of Kentucky has as its objective the development of such a method. The first phase of the project included an appraisal of all known previous work in the field of dynamic weighing. This article reviews the development of the dynamic electronic scale and the experiences of a number of State highway departments with its practical use. Recent experimental developments in this country and Europe are described and evaluated. Some conclusions are reached and the future course of the Kentucky project is outlined.

Introduction

WHAT IS THE BEST and most practical method of weighing a moving vehicle? Should new equipment be developed for this purpose or can existing devices be modified to do the job? The answer to these and other questions on the subject are being sought by a research team at the University of Kentucky's College of Engineering.[1]

Working under joint sponsorship of the Kentucky Department of Highways and the Bureau of Public Roads, the team is conducting its investigations along these general lines:

An examination and appraisal of all known types of commercial and experimental dynamic weighing systems.

The design and construction of a test installation on an Interstate System route.

An exhaustive testing program, utilizing various types of dynamic scales and allied equipment.

Analysis of the test results, with the objective of developing specifications for a model dynamic weighing station.

The first step, collection of all available information on the subject of dynamic weighing, has been completed. It is realized, however, that some unpublished or unpublicized work may well have been missed by the research staff, and information on any such additional material for study would be appreciated.

After study of the available literature, a number of inspection trips were made to existing installations. This article summarizes the findings from both approaches, draws some conclusions, and outlines the future course of the project.

Purposes of Dynamic Weighing

The problem of weighing moving vehicles has received the attention of many agencies and individuals concerned with the planning and operation of our highway systems. A knowledge of the magnitude and frequency of application of wheel loads to the highway surface is of major importance in the structural design of the pavement cross section, and in anticipating future maintenance problems. This information is generally obtained at present by stopping a small sample of the passing vehicles and measuring the wheel loads with a portable scale or loadometer. The cost of weighing a 200-vehicle sample by this method has been estimated at about $150 per day (*1*)[2]. Obviously, an efficient dynamic weighing system in continuous operation would permit the collection of data for a much larger sample at a greatly reduced operating cost.

The trucking industry and the load limit enforcement agencies of the several States are also interested in the development of a dynamic scale that will determine axle weights of vehicles in the traffic stream with an accuracy sufficient to permit detection of overloads. Those trucks loaded near or above the legal limit could then be stopped for check weighing at a conventional static scale, if necessary for legal reasons. Empty or lightly loaded vehicles could proceed with little or no delay. The importance of this is emphasized by the fact that during one 14-week period in Illinois, over a million vehicles were stopped unnecessarily for weighing in connection with load-limit enforcement. Only 0.2 percent of the vehicles weighed were overloaded (*1*).

The Electronic Scale

The most widely used dynamic weighing device is the electronic scale. This type of scale has been used by industry for over a decade in the static weighing of such diverse items as steel, coal, cement, and aircraft; and for both dynamic and static weighing of railroad freight cars (*1*). The electronic scale will measure static weights with an accuracy equal to or better than that of the lever system scale. It is also light in weight and contains no levers, knife edges, or other mechanical parts requiring periodic adjustments due to wear.

As shown in figure 1, the basic weight sensing element of the electronic scale is the resistance wire strain gage, which is an encased fine wire grid mounted on a paper backing and covered with felt. When a load is applied to a structural member, to which the strain gage is cemented, the wire in the gage is lengthened or shortened a minute amount. This change in length results in a measurable change in the resistance of the wire, which is proportional to the applied load.

An important application of this principle for weighing purposes is in the commercially developed "load cell." The load cell, illustrated in figure 1, consists primarily of a short steel column to which are bonded resistance wire strain gages. The gages are so arranged that in each cell they form a resistance network commonly known as a Wheatstone Bridge. When the network is balanced, the voltage output of the cell is zero. When a load is applied to the cell the bridge becomes electrically unbalanced, resulting in a tiny voltage output which can be amplified and translated into an indication of weight.

The typical electronic scale consists of a rectangular platform supported at each of its corners by a load cell. The type of detecting and recording apparatus used depends upon the object being weighed and the kind of output

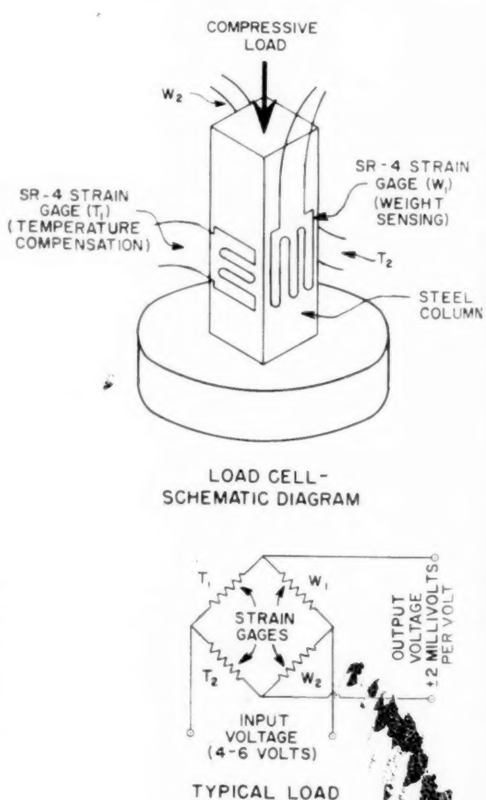

Figure 1.—The strain gage load cell

[1] Members of the research team are David K. Blythe, Civil Engineering Department Head, project director; John A. Dearinger, Assistant Professor of Civil Engineering, assistant project director; Russell E. Puckett, Assistant Professor of Electrical Engineering, electronics engineer; and Charles C. Schimpeler, graduate student in civil engineering, research assistant.

[2] Italic numbers in parentheses represent references, page 210.

desired. The scales for weighing cement and livestock, for example, use a printed card output (*2*). Most of the scales used for dynamic weighing are equipped with a recording oscillograph which records a weight as the peak reading of a stylus trace on paper tape. A typical oscillograph record is shown in figure 2.

Development of Dynamic Weighing

The pioneer effort in the development of a dynamic weighing device for highway use was made by O. K. Normann and R. C. Hopkins of the Bureau of Public Roads, who, in 1951, installed an experimental scale in the Shirley Highway near Washington, D.C. (*3*).

This scale consisted of a 3-foot long (in the direction of traffic) by 10-foot wide concrete platform, supported on four load cells (see fig. 2). The electronic apparatus used was part of a portable kit designed for the static weighing of aircraft. The scale was calibrated so that the axle weights of a vehicle passing over the platform were shown as individual peaks in an oscilloscope pattern. Recording was accomplished by photographing the pattern at the time of the vehicle's passage. A pair of air switches, actuated by road tubes, provided automatic starting and stopping of the equipment, and enabled speed and axle spacing to be determined.

Accuracy tests were conducted by comparing the static axle weights of a 2-axle test vehicle with the dynamic weights recorded by the electronic scale, at vehicle speeds ranging from 10 to 50 miles per hour. The average difference between the weight recorded and the actual static weight was about 5 percent, and seemed to be independent of speed. A much larger variance was noted for the second and third axles of a 3-axle vehicle; this was thought to be due to the vibrations set up in the platform by the first axle. Horizontal tie-bars and vertical pre-loading bolts added to the platform succeeded in reducing the size of these differences by about 50 percent.

Further testing of the scale resulted in a number of recommendations for improving its design and operation. These recommendations were incorporated into a second scale constructed near Woodbridge, Va., by the Virginia Department of Highways in cooperation with the Bureau of Public Roads and an electronic equipment manufacturer. Major changes in the design of this scale included lengthening the platform to 7 feet (in the direction of traffic) and the use of a recording oscillograph instead of the oscilloscope and camera. The Woodbridge scale was used by the Public Roads research staff in their search for the best method of measuring variations in the dynamic loading of the highway surface (*4*).

Test data from the original scale had shown that the dynamic weights recorded varied from the static weights in a random manner—the recorded dynamic weight of an axle might be greater than, less than, or equal to its static weight. This indicated that the vehicles were oscillating as they crossed the platform, and that the scale was actually sampling the applied pressure at random points in the vehicle's oscillation cycle. This was verified by measuring dynamic load variations through air pressure changes in the tires of a moving vehicle and comparing these variations to the simultaneous weight recordings of the scale.

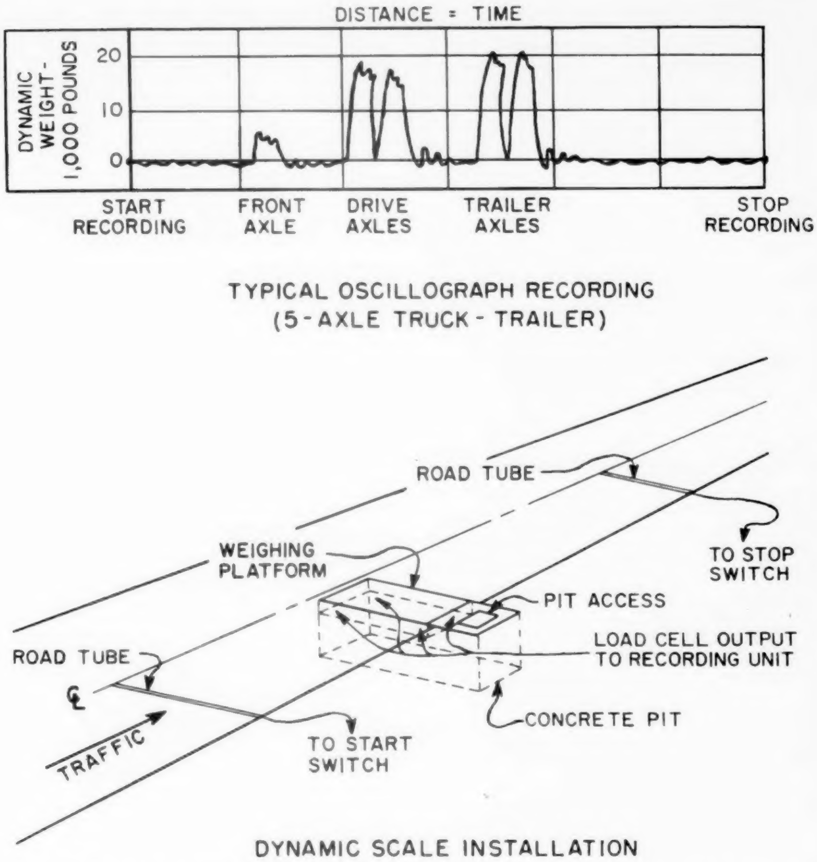

Figure 2.—Highway installation of a dynamic weighing scale.

It was also found that the number of cycles through which the vehicle oscillated as it crossed the 7-foot platform was dependent upon speed and pavement roughness. For speeds over 20 miles per hour, less than one-half of a complete cycle occurred while the vehicle was on the platform. Rough approach conditions tended to decrease the frequency of the oscillations with a corresponding increase in their amplitude. The reverse was true for smoother approach surfaces.

These findings were significant. Since the dynamic weights ranged above and below the static weights in an unbiased way, the differences or "errors" would tend to cancel out of the sum of a number of recorded axle loads. Gross tonnage information needed by highway planners could thus be obtained on the electronic scale with an accuracy equal to that of the slower and more costly loadometer method. It was also made clear that a smooth approach to the scale platform was a necessity if a closer agreement between static and dynamic weights was to be realized.

Dynamic Weighing in the United States

Encouraged by the results of the Bureau of Public Roads experimental work, a few electronic equipment firms began manufacturing scales for dynamic weighing. These scales were all of the same general design as the Public Roads prototype—a short rectangular platform supported by load cells.

With the advent of the commercially available scale, several State highway departments became interested in its application to their particular problems. First to attempt the practical use of the dynamic scale were the States of Iowa, Minnesota, and Oregon. The degree of success attained by these States in their dynamic weighing operations appears to have depended mainly upon the type of information they were trying to obtain.

It was generally agreed that the electronic scale might well be used for one or more of the following purposes:

Dynamic weighing to obtain weight data for research and planning.

Dynamic weighing to detect overloaded trucks.

Static weighing for enforcement of legal weight limits.

As will be seen, these three States, in the course of their experiences with the device, have investigated rather thoroughly the practical side of each of these possibilities. All of these States completed their initial installations at about the same time (in the fall of 1954) and all used, with individual minor variations, scales manufactured by the same electronics firm.

Iowa experience

The Iowa State Highway Commission has used the electronic scale for the collection of dynamic axle-load data for planning purposes exclusively (*5*). They now have three scales

in operation and are planning to install seven others. This agency uses a single set of amplifying and recording instruments housed in a converted school bus (*6*). Connection to the load cells of an individual scale is made through a weatherproof junction box mounted on the road shoulder. Iowa plans to use this combination of strategically placed dynamic scales and a mobile recording unit as an eventual replacement for their loadometer crews. Official opinion in this State is that the dynamic weights recorded by the scale represent the actual loads applied to the highway and are therefore more useful in planning and design than are the static axle loads. No attempt has been made to use the scales for enforcement purposes.

Comparisons of static and dynamic weights recorded at the Iowa scales showed that 20 percent of the vehicles were "overweighed" by more than 5 percent, while only 5 percent were "underweighed" by more than 5 percent. Dynamic weights recorded for 50 percent of the vehicles fell within 2 percent of the corresponding static weights.

Though few maintenance problems have been encountered in Iowa, the need has been expressed for an improved method of recording the data. A continuous output in the form of a punched card or printed tape would reduce the many hours of tedious work now required to extract weight data from the oscillograph tapes.

Minnesota experience

The Minnesota Department of Highways has been using the electronic scale for all three of the purposes listed above (*7*). An installation near St. Paul uses one scale as a detector to cull out overloaded trucks, and another located 1,500 feet down the highway as a static scale for check weighing the suspected violators. The detector scale is set so that the passage of a truck whose indicated weight is above the legal limit causes a sign to flash on, directing the vehicle to go to the static scale. The violation is also indicated to the scale operator by a warning light. Fines collected from the operators of overloaded vehicles detected by this setup amounted to nearly $15,500 during a 3-month period. This represents over half of the cost of the entire installation.

A second set of electronic scales, one dynamic and one static, placed in a major highway west of Minneapolis, is used to collect wheel-load data for planning and research. Minnesota highway engineers feel that the collection of this type of information is of such importance as to more than justify the cost of the scales.

Minnesota has found that crossing speeds above 55 miles per hour resulted in inaccurate weight recordings. As this was due to the effect of momentum on the sweep of the recording stylus, the speed limit was reduced to 40 miles per hour in the vicinity of the detector. Traffic was channelized to assure that all of the wheels of a given truck would pass over the detector platform.

Maintenance problems in Minnesota have been chiefly caused by the effects of extreme cold on the recording equipment. This has been lessened by insulating the instrument housings, and by using an instrument van similar to Iowa's (*8*).

Oregon experience

Oregon's experience with weighing moving vehicles began in September 1954, when two electronic scales were placed in a highway near Oregon City (*9*). These scales were used to collect wheel-load data for a long-range pavement performance test.

Calibration was accomplished by using a truck-trailer combination of known static axle weights, and a large trucking concern agreed to run their scheduled vehicles over the scales. This provided a sizable sample of known axle loads, in various combinations of size and spacing. Statistical analysis of the data collected during this period enabled the calculation of "correction factors" for converting the recorded dynamic weights to equivalent static weights. The correction factors averaged about 1,000 pounds for the particular traffic and speed range existing at this location. This was considered of sufficient accuracy for research purposes.

Many maintenance problems arose during the first year of operation of the Oregon scales. A report published at the end of that time stressed the difficulty in leveling the platform. The four-point support requires that the tops of the load cells be adjusted to within 0.001 inch of the same elevation, so that each cell will carry an equal share of the dead load. Oregon's trouble occurred because at the initial placement of the platform, no way was provided to make subsequent leveling adjustments. Difficulties were also precipitated by accumulation of moisture in the scale pits, resulting in deterioration of the load cells and of the circuitry, and by failures in the electronic equipment due to variances in the voltage supply.

The original two scales were eventually removed and reinstalled, along with an additional two, in the Baldock Freeway. These four scales were operated 16 hours each month for a period of 20 months. The same troubles originally encountered continued to preclude the successful operation of the scales. The expense of maintaining the equipment under these conditions became prohibitive, and the weighing operations were discontinued in early 1958 (*10*).

Other installations

On the Indiana Toll Road, a slightly different type of scale is now being used at the toll plazas for detecting overloaded vehicles. This scale was manufactured by a firm specializing in toll collection equipment. The steel platform is supported on four moisture-proof load cells, and can be adjusted positionally in three directions by a system of tie bolts. The weight sensing elements of the scale can be preset to a given weight limit, and cause an alarm to be sounded when the limit is exceeded. Also featured is an automatic print-out, recording the vehicle's passage, time, place of entry, and other pertinent data.

Other potentially fruitful studies have been under way in the United States. Among these are the electronic scale installations used for research at the AASHO Road Test and at the Michigan State Highway Department Research Laboratory, and the study of road loading mechanics conducted at the Cornell Aeronautical Laboratory.

The setup at the AASHO Road Test, which was not built specifically for weighing vehicles in motion, consists of three scales. Two of these are used for the static weighing of the tandem axles of the test vehicles. The third scale has served as a calibration instrument for the tire-pressure measuring equipment used in the study of variations in pavement loading. Informal tests conducted by the scale manufacturer, shortly after construction was completed, showed differences of up to 20 percent between the static and dynamic weights of a 30,000-pound axle. Although the physical facilities and instrumentation of the Road Test offered a unique opportunity for full exploration of the problem of dynamic weighing, the primary interest has necessarily been in other areas, and the electronic scale has served only as a useful tool.

While the AASHO Road Test is mainly concerned with the effect of the vehicle upon the road, Michigan engineers are investigating the reverse situation; that is, the stresses and strains induced in a vehicle by varying pavement conditions. The scale used in this work has a 7-foot long steel platform which weighs approximately the same as a section of pavement of the same dimensions. Impact is introduced by placing wood strips of various thicknesses on the platform during the test runs. Dynamic weights recorded by the scale are used to check those obtained through tire-pressure variations on the test vehicle.

The Cornell Aeronautical Laboratory, in its study of road loading mechanics (*11*), has been investigating the cause and effect of the high percentage of variation of dynamic axle weights from their corresponding static weights. These studies have been made by the use of mathematical models representing typical vehicles and road surface conditions. The preliminary findings show that for the same surface roughness, the maximum ratio between dynamic weight and static weight may range from 1.5 for a rear loaded truck with shock absorbers to 7.5 for an empty truck with no shock absorbers. Actual experience with dynamic weighing, however, has not revealed consistent variations of this size, although differences of 20 to 50 percent are common.

Other American Dynamic Scales

Several attempts have been made to weigh moving vehicles by means other than the floating-platform electronic scale. Work of this nature has been the subject of at least two theses for civil engineering master's degrees in the last 4 years.

With the perfection of the resistance wire strain gage, and instruments to detect and record its output, it became feasible to measure the actual stresses produced in a structure both by stationary and by moving loads. One of the first studies of this type was conducted by the University of California on the San Leandro Creek Bridge near Oakland (*12*).

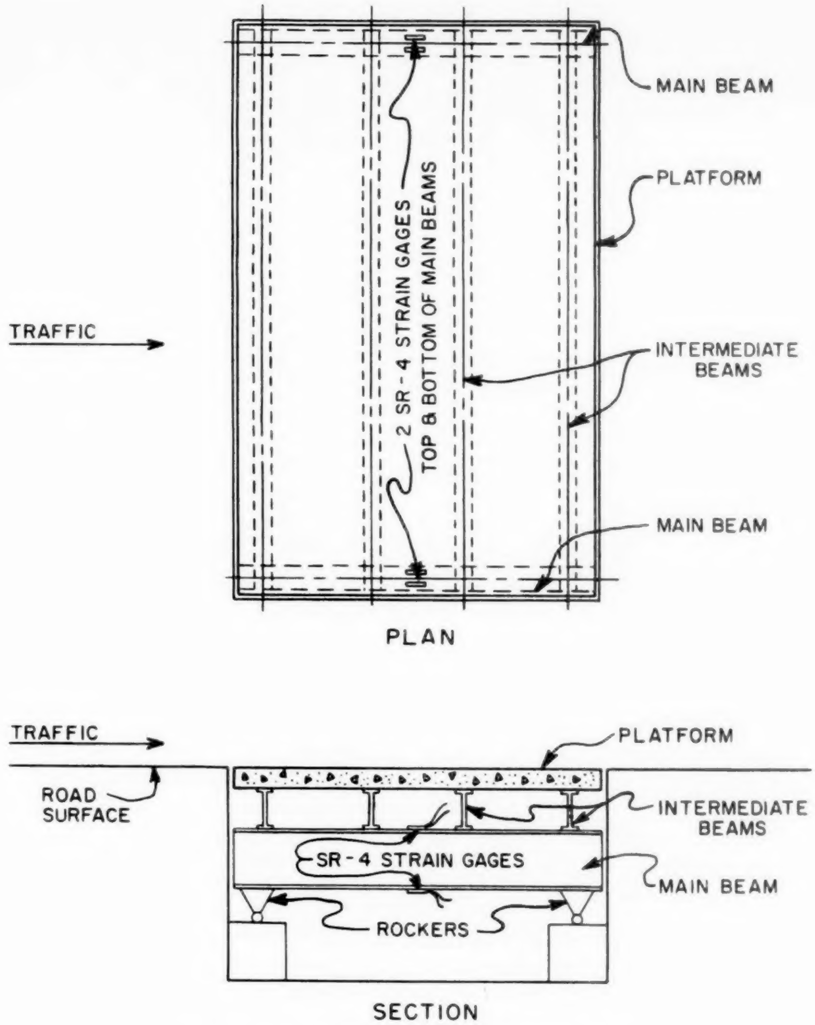

Figure 3.—Experimental beam-type scale.

Part of the study was concerned with the effect of dynamic loads transmitted to the bridge structure by a moving vehicle. This was done very effectively by attaching strain gages to the supporting girders and using a recording galvanometer to present the gage output in a form which could be interpreted.

This same process was used by a University of Kentucky graduate student to weigh moving vehicles (*13*). Strain gages were attached to the steel I beams supporting the platform of an existing lever-type scale, as shown in figure 3. The weight of a vehicle moving over the platform resulted in a momentary strain in the beams due to bending. The gage output, under strain, was recorded by a light-beam galvanometer similar to that used in the San Leandro study. It was reasoned that the deflections of the galvanometer would be proportional to the applied load.

After calibration, test runs were made with a heavy vehicle moving across the platform at speeds varying from 10 to 50 miles per hour. The results showed variations ranging to over 30 percent between dynamic and static weight. This experiment indicated that it was practical to measure dynamic loads through the bending in a simple beam, and opened the way for a more thorough investigation of the possibilities of the use of the strain gage as a weight-measuring device in this manner.

Dynamic weighing has also been the subject of a thesis by a Mississippi State College student (*14*), who designed and built a portable scale consisting of a series of small, flat load cells sandwiched between two 17- by 41-inch metal plates. Each load cell was fabricated from a ½-inch length of 2-inch diameter steel shaft. Load was applied to each cell through a spherical segment cut from a ball bearing, embedded (flat side down) in the top center of the cell. The load was measured by a strain gage attached to a recess cut into the bottom of the cell opposite the bearing point. The scale was embedded in the pavement along the right wheel track of the traffic lane and was tested by running a truck over it at speeds of 10, 20, and 30 miles per hour. The output of the scale's load cells was fed into a high-speed recorder which indicated the results on paper tape. Since the stylus deflection of the recorder did not bear a linear relationship to the applied load, it was not possible to obtain a good check on the accuracy of this experimental scale. Low cost of constructing the scale, portability, and particularly the fact that no pit is required, would seem to justify further study of a device of this type.

European Dynamic Scales

Some of the most promising advances in the field of dynamic weighing have taken place in England and Germany. Here the primary interest has been in the collection of axle-load data for research and planning purposes.

The Road Research Laboratory in England has recently built an electronic scale which will detect a moving axle load and classify it into one of eleven weight groups (*15*). The scale employs a platform and load cells similar to those used in the United States, but the entire unit is built of lightweight materials for maximum portability. Its recording equipment consists of a mirror galvanometer, 11 photoelectric cells, and the same number of mechanical registers. The output of the scale's load cells causes the galvanometer to deflect, moving a beam of light over the bank of photo cells. The photo cells are connected through a transistor circuit to the mechanical registers. The registers automatically increase their count by one as the light beam activates successive photo cells. The upper limit reached by the deflected beam, therefore, represents the weight group into which the axle load falls. The final readings of the registers represent the sum of the number of loads in each weight group, and the total number of loads falling into higher groups. The actual number of loads in each group is obtained by subtraction.

The major advantage of this scale over most of the American models is the possibility of automatic recording over a longer period of time. The results can be read directly without further interpretation. Accuracy is rather limited, and the percent of error ranged above 10 percent for this scale.

What is perhaps the most sophisticated dynamic scale in use today was developed and built in 1958 by a West German research organization (*15*), which was called upon to design a scale that would measure the axle weights of moving vehicles in such a way that: (1) Axles could be weighed separately, even at high speeds; (2) axle loads could be grouped, as with the British scale; (3) results could be read as a total count in each group; and (4) continuous weighing and recording would be possible.

To meet these criteria, a "broken bridge" platform, as illustrated in figure 4, was used instead of the monolithic type common to all known previous scales. The "broken bridge" consists of a steel platform split, at right angles to traffic, into two sections of equal width. The outside edge of each section rests, near the corners, on a hinged support similar to a bridge rocker. The contiguous edges are supported, through interlocking bearing plates, by two strain gage load cells. The platform sections are held in position by heavy springs anchored to the floor of the pit. As a load comes on the platform, the load cell output increases linearly until a maximum is reached when the load is directly over the joint between the two sections. As the load moves off the scale, the cell output decreases linearly to zero. The dynamic weight is therefore

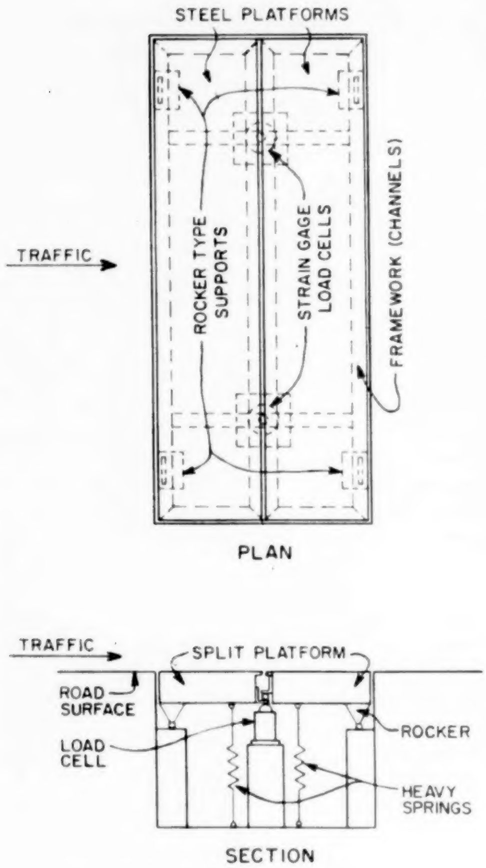

Figure 4.—"Broken bridge" scale.

measured by the maximum load cell output recorded at the center of the platform.

The curve representing cell output (weight) is triangular in shape rather than trapezoidal as in the case with the monolithic platform, as shown in figure 5. This permits a more accurate determination of the dynamic weight, as the maximum reading is represented by a sharp peak rather than by some point on an irregularly sloping line. Another advantage of the broken bridge platform is that it does not tend to vibrate as much as the monolithic type under either heavy or light axle loads.

The recording system of the German scale provides for sorting the axle loads into six groups, covering a weight range from 0.3 ton to over 12 tons. A finer division was possible but was not needed in this particular application. The alternating current input to the load cells results in the axle load being represented as an amplitude-modulated signal. This signal is amplified, demodulated, and amplified again. Load curves may be recorded at this point. The signal is then fed into a sorter which places it in the proper load group and records the event through a relay-actuated mechanical counter. The number of loads in each load group may then be read at any time. Other electronic components include optical recorders for each load group, a calibration unit, and a device which automatically corrects zero point drift.

The maximum speed at which individual axle weights can be determined by any electronic scale depends upon the platform length, the response time of the equipment, and the spacing of the axles. For the German scale, with a platform length of 4.6 feet and a counting frequency of 25 counts per second, this top speed is about 78 miles per hour, provided that the axle spacing is greater than 4.6 feet. More closely spaced axles would have to be weighed at much lower speeds if separate weight recordings were desired.

Tests have shown that the dynamic weights obtained from the broken bridge scale are generally within 5 percent of the comparable static weights. Recognizing the importance of reducing the impact factor (dynamic weight/static weight) to as near unity as possible, the German engineers stress the necessity of a smooth approach to the scale platform.

The broken bridge scale described here has been in operation on highway B29 near Grumbach since 1958, and similar installations are planned for major highways near Darmstadt and Dusseldorf.

Conclusions

Based on a study of the experiences of others, discussions with highway and electronic engineers and scale manufacturers, and from personal inspection of various dynamic weighing facilities, the following conclusions seem valid:

1. A properly designed and instrumented electronic scale will measure the actual load applied to the scale platform within certain limits of accuracy. To state this more specifically:

Static loads may be measured as accurately as with conventional lever system scales.

Individual dynamic axle weights may vary from the corresponding static weights by a large percentage.

The total gross weight of a number of axles passing over a section of highway during an extended period of time (and thus their average weights, in weight groups) can be obtained by dynamic weighing, with accuracy sufficient for research and planning purposes. Several agencies have reported average variations between gross dynamic and static weights of 2 percent or less. Commercially available electronic scales, using strain gage load cells, can perform this particular data-gathering function quite well, although the recording methods need to be improved.

2. In the field of overload detection for enforcement purposes, the performance of the electronic scale has been only fair. For this purpose, it would be desirable to maintain the maximum difference between dynamic and static weights at 5 percent or less. A method of damping the vehicle's oscillations, either directly by providing a smooth approach surface, or indirectly through instrumentation, is needed to reduce the variance to this limit. Results obtained in Germany with the broken bridge scale seem to offer some prospect for solution of this problem.

3. Major maintenance and operation problems encountered in previous dynamic scale installations included the damaging effects of moisture on load cells and circuitry; the difficulty of keeping the platform level; movement of the platform upon impact of the vehicle; platform vibration under tandem axles; unsatisfactory recording methods; and the necessity for constant attendance by a skilled operator. Most of these problems have been attacked with varying degrees of success by both the scale manufacturers and the users. Specifications for a model installation should use the findings from this previous work and provide additional solutions where needed.

Future Research Planned

The University of Kentucky research team has planned the study of several dynamic weighing devices. One of these will be a commercially available electronic scale, the testing of which will emphasize the effects of weather and constant traffic upon the per-

(Continued on p. 210)

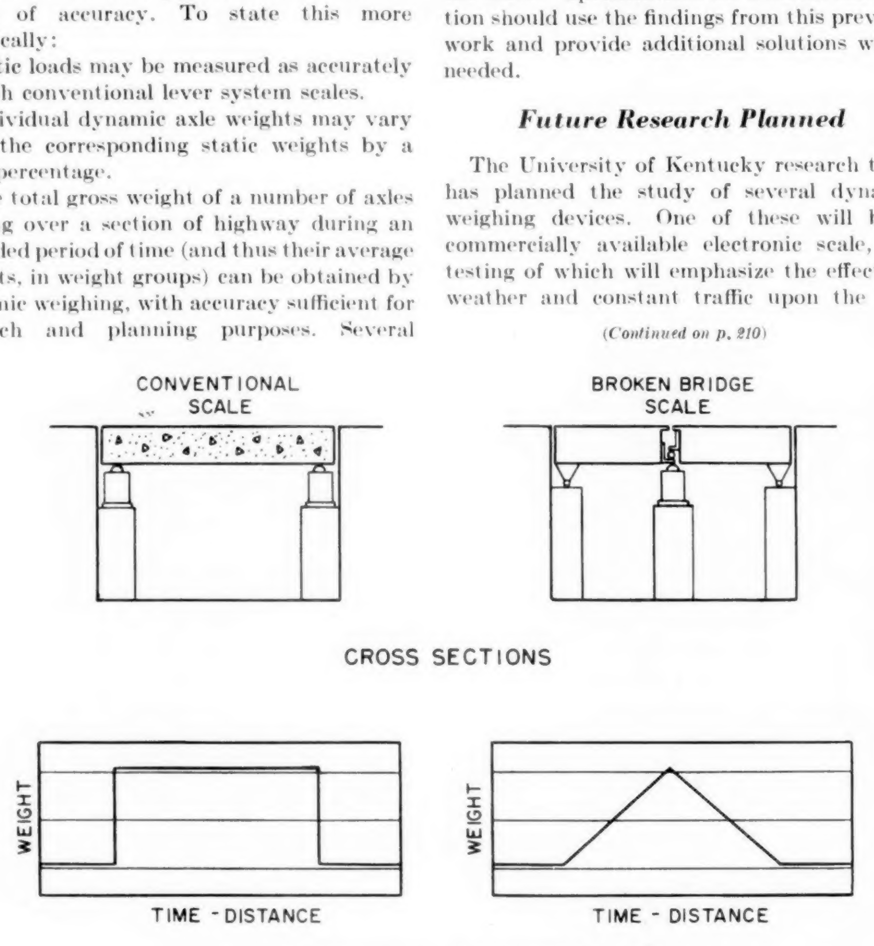

Figure 5.—Comparison of conventional and broken bridge scale dynamic weight recordings.

Concrete Containing Fly Ash as a Replacement for Portland Blast-Furnace Slag Cement

BY THE DIVISION OF PHYSICAL RESEARCH
BUREAU OF PUBLIC ROADS

Reported [1] by WILLIAM E. GRIEB and DONALD O. WOOLF, Highway Research Engineers

This article reports a study of the use of fly ash as a replacement for part of the cement in concrete mixes prepared with portland cement and portland blast-furnace slag cement, and tests of a recommended adjusted mix containing fly ash. The results show that fly ash can be used satisfactorily as a replacement for portland or slag cement, but the properties of the concrete are affected by the carbon content of the fly ash. It is indicated that the amount of fly ash used should be correlated with the amount of lime released by the portland cement.

Introduction

A REPORT ON A STUDY of the use of fly ash in concrete was published in PUBLIC ROADS in 1957.[2] That article covered the properties of concrete prepared with each of four fly ashes, as replacements for either one-third or one-sixth of the volume of the portland cement used in the mix. The fly ashes differed widely in carbon content. Two type I portland cements were used, one having a high alkali content and the other a low alkali content.

Following issuance of that report, several questions were raised which resulted in the undertaking of further tests.

One of the questions was whether fly ash could be used as a replacement for part of the cement in concrete mixes prepared with portland blast-furnace slag cement. This cement is defined as an intimately interground mixture of portland cement clinker and granulated blast-furnace slag. The slag content in the final product is limited to a range of from 25 to 65 percent by weight.[3] The finely ground slag is by itself only slightly cementitious. Concern was expressed over the possibility that a further dilution of the cement constituent, by replacing part of this cement with fly ash, might cause the concrete to have unfavorable strength characteristics. Although fly ash has a pozzolanic reaction with lime liberated by portland cement during hydration, there was a question of whether sufficient lime would be available for this reaction.

In the first part of the investigation reported in this article, tests identified as Series I were made on concretes prepared with portland cements and with portland blast-furnace slag cements in which one-third of the cement (by volume) was replaced by fly ash.

The investigation reported in 1957 had indicated that a direct replacement of either one-sixth or one-third of the portland cement by fly ash resulted in reduced strength of the concrete at all ages through 28 days. It was also found that replacement of one-third of the cement by fly ash adversely affected the resistance of concrete to attack by calcium chloride used for ice removal.

In a discussion of that study, a producer of fly ash recommended the use of an adjusted mix containing fly ash, which reportedly would furnish good early strength and resistance to scaling in concrete. In this mix, the cement content was reduced from 6.0 to 5.25 bags per cubic yard, the sand-to-total aggregate ratio was reduced by 2 percent, and an addition of 100 pounds (approximately 1⅓ bags) of fly ash was made. To determine the effect of this mix on the durability and strength of concrete, tests identified in this article as Series II were made.

Conclusions

These two series of tests verify some of the conclusions of the previous report: mainly, that the properties of the concrete are affected by the carbon content of the fly ash used as a replacement for part of the cement. Lower strengths and durability were obtained with concrete containing the high-carbon fly ash than when the low-carbon fly ash was used.

Fly ash can be used as a replacement for a part of the portland blast-furnace slag cement without serious decrease in the strength or durability of the concrete.

Concrete prepared with low-carbon fly ash as a replacement for portland cement, in the amounts recommended by the producers of fly ash, has compressive and flexural strengths at 28 days equal to similar concrete without fly ash.

The recommended amount of fly ash, if low in carbon content, also produces concrete which has resistance to scaling, caused by the use of de-icing agents, equal to that of similar concrete without fly ash.

Tests for strength and durability of concrete indicated that, for optimum effectiveness, the amount of fly ash used should be correlated with the amount of lime released by the portland cement. If sufficient lime is not available to react with all of the fly ash, some of the latter is only an inert filler, and tends to impair the quality of the concrete.

It is suggested that the amount of fly ash used should be about 15 percent by weight of the calcium oxide content of the cement, as determined by chemical analysis. This amount may vary somewhat according to the chemical composition of the aggregates.

Materials

In this investigation, tests for compressive and flexural strength and for durability were made on air-entrained concrete mixes prepared with two fly ashes and four cements. The fly ashes were similar to those used in the previous investigation, but different cements were used.

The two fly ashes used were identified as B and Y, and corresponded to fly ashes B and Y used in the previous investigation. Fly ash B had a low-carbon content (0.6 percent) and fly ash Y had a high-carbon content (11.2 percent). ASTM Specification C 350–60 T limits the loss on ignition of fly ash to 12 percent. (The loss on ignition is due mainly to carbon.) Both fly ashes met this requirement.

The cements used were a type I portland cement and a type IS portland blast-furnace slag cement, from each of two cement plants. At each plant, the same clinker was used in the manufacture of the two types of cement. These cements were identified as cements B–I and B–IS, and E–I and E–IS, and corresponded to the cements of the same identification reported in a previous investigation of portland blast-furnace slag cement in concrete.[4] The two cements from source B were low-alkali cements and those from source E were high in alkali. The chemical composi-

[1] Presented at the 64th annual meeting of the American Society for Testing Materials, Atlantic City, N.J., June 26–30, 1961.

[2] *Use of Fly Ash in Concrete*, by A. G. Timms and W. E. Grieb; PUBLIC ROADS, vol. 29, No. 6, Feb. 1957, p. 142.

[3] Definition of portland blast-furnace slag cement in ASTM C 205–58 T.

[4] *Tests of Concrete Containing Portland Blast-Furnace Slag Cement*, by W. E. Grieb and George Werner; PUBLIC ROADS, vol. 31, No. 9, Aug. 1961, p. 183.

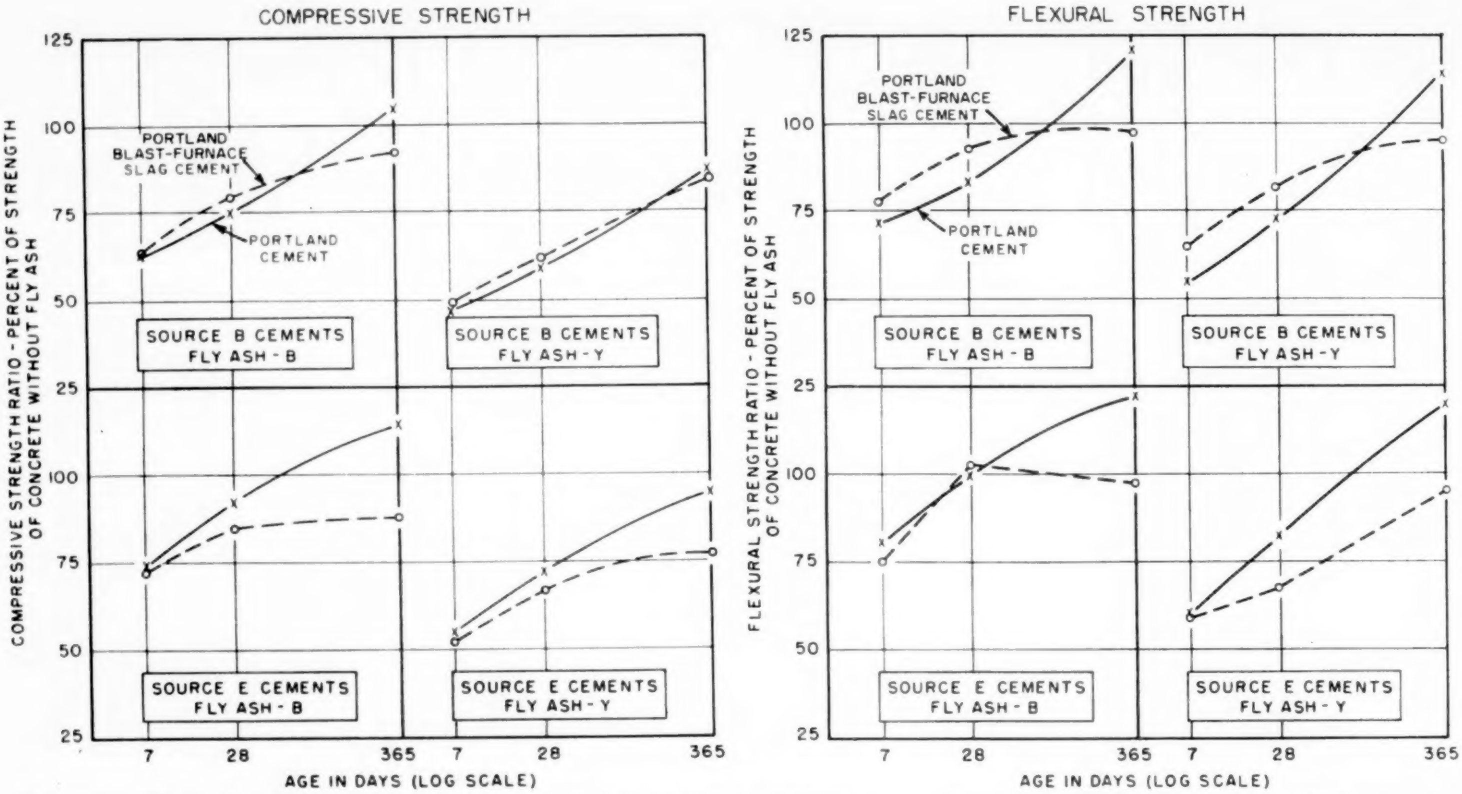

Figure 1.—Effect of replacement of one-third of portland or portland blast-furnace slag cement by fly ash on strength of concrete.

tion and physical properties of these fly ashes and cements are given in table 1.

The aggregates were similar to those used in the previous investigation. They were a siliceous sand and a crushed limestone. The concretes for strength tests were made with 1½-inch maximum size coarse aggregate, and for durability tests the maximum size was 1 inch. A commercially available aqueous solution of neutralized Vinsol resin was used to entrain air.

Mix Proportions

The mix data for all concrete specimens are given in table 2. All tests were made on air-entrained concrete. The control mixes without fly ash were designed for a cement content of 6.0 bags of cement per cubic yard of concrete with a slump of 3 inches and an air content of 5 percent.

In the Series I tests, one-third of the cement was replaced by fly ash; thus in the 6-bag mix, 2 bags of cement were replaced by an equal solid volume of fly ash. Because of the differences in the specific gravities of the materials, 74 pounds of fly ash B or 72 pounds of fly ash Y was equivalent to the solid volume of a 94-pound bag of cement. The weights of the fine and coarse aggregates per cubic yard of concrete were the same for the mixes with and without fly ash.

One-third replacement of fly ash is more than would ordinarily be used in highway construction. However, if this amount could be used without detrimental effects, it would be obvious that lesser amounts could also be used.

For the Series II tests, the control mixes without fly ash were the same as those used in Series I. Where fly ash was used, the mix was adjusted as recommended by the producers of fly ash. Three-quarters of a bag of cement (70.5 pounds) was replaced by 1⅓ bags of fly ash (100 pounds), and to compensate for the greater volume of fly ash as compared with the volume of cement replaced, the sand content was reduced by approximately 45 pounds per cubic yard. The weight of the coarse aggregate per cubic yard of concrete was the same for the mixes with and without fly ash.

Table 2 shows that for both Series I and II, the mixes prepared with fly ash B generally required slightly less water than was required for the corresponding mix without fly ash. Where fly ash Y was used, slightly more water was generally required than for the mix without fly ash. This was true both for the con-

Table 1.—Chemical composition and physical properties of cements and fly ashes

	Portland cements		Portland blast-furnace slag cements		Fly ashe	
	B-I	E-I	B-IS	E-IS	B	Y
Chemical composition (percent):						
Silicon dioxide	20.8	21.3	26.2	26.1	49.2	38.5
Aluminum oxide	5.1	5.6	7.8	6.7	19.9	23.5
Ferric oxide	3.1	3.5	2.3	2.4	16.2	18.8
Calcium oxide	63.6	62.5	53.6	55.7	5.5	3.2
Magnesium oxide	2.8	1.7	3.6	2.8	1.4	1.0
Sulfur trioxide	1.8	2.3	2.3	2.2	2.7	.6
Loss on ignition	1.6	1.3	2.0	2.2	[1] 1.2	[1] 11.6
Sodium oxide	.09	.15	.09	.15	2.00	.60
Potassium oxide	.15	1.02	.20	.91	2.35	1.88
Total equivalent alkalies as Na_2O	.19	.82	.22	.75	3.55	1.84
Insoluble residue	.16	.20	.73	.26	------	------
Chloroform-soluble	.003	.003	.006	.008	------	------
Carbon	------	------	------	------	.6	11.2
Computed compound (percent):						
Tricalcium silicate	57	43	------	------	------	------
Dicalcium silicate	17	28	------	------	------	------
Tricalcium aluminate	8	9	------	------	------	------
Tetracalcium aluminoferrite	9	11	------	------	------	------
Calcium sulfate	3.1	3.9	------	------	------	------
Slag used in manufacture (percent)	------	------	45	35	------	------
Physical properties:						
Apparent specific gravity	3.12	3.14	3.03	3.03	2.52	2.43
Specific surface (Blaine) cm.²/g.	3,325	3,555	4,820	3,605	4,305	3,220
Passing No. 325 sieve percent	87.5	96.2	97.6	94.9	95.2	89.4
Autoclave expansion percent	0.06	0.04	0.00	0.00	------	------
Normal consistency percent	23.8	26.5	27.2	26.6	------	------
Time of setting (Gillmore):						
Initial hours	3.7	2.9	3.4	2.8	------	------
Final hours	5.6	4.8	6.2	6.2	------	------
Compressive strength (1:2.75 mortar):						
At 7 days p.s.i.	2,625	3,525	2,630	2,360	------	------
At 28 days p.s.i.	4,150	4,965	5,190	3,900	------	------
Mortar air content percent	10.4	9.4	7.4	9.2	------	------

[1] Determination made at 600° C.

Table 2.—Concrete mix data

Cement			Fly ash		Mixes for strength tests [1]					Mixes for durability tests [1]				
Identification		Amount	Identification	Amount used	Water used	Slump	Weight of plastic concrete	Air content	A.E.A. used [2]	Water used	Slump	Weight of plastic concrete	Air content	A.E.A. used [2]
Source	Type													
SERIES I														
		Bags/cu. yd.		*Lb./cu. yd.*	*Gal./cu. yd.*	*In.*	*Lb./cu. ft.*	*Pct.*	*Pct.*	*Gal./cu. yd.*	*In.*	*Lb./cu. ft.*	*Pct.*	*Pct.*
B	I	6.0	None	None	31.2	3.1	146.8	4.6	100	34.4	2.4	145.5	4.9	100
		4.0	B	148	31.0	3.3	146.2	4.7	202	31.3	2.0	144.9	5.8	171
		4.0	Y	144	31.5	3.0	145.4	5.2	617	35.8	2.9	144.7	4.2	500
B	IS	6.0	None	None	31.9	2.9	147.2	4.8	100	35.3	2.9	145.5	4.2	100
		4.0	B	148	29.8	2.9	146.8	4.2	104	35.2	2.7	143.5	5.9	129
		4.0	Y	144	31.5	2.7	145.1	4.8	239	34.1	2.6	140.2	6.7	321
E	I	6.0	None	None	31.5	2.9	147.4	5.4	100	34.5	2.6	145.5	5.1	100
		4.0	B	148	31.3	2.9	147.5	4.7	138	32.7	2.5	145.5	5.2	157
		4.0	Y	144	32.1	3.0	145.9	5.1	447	35.9	2.6	144.7	4.9	429
E	IS	6.0	None	None	31.6	2.8	146.4	5.1	100	35.0	2.8	143.5	5.8	100
		4.0	B	148	30.4	3.3	146.6	4.6	169	33.0	3.2	142.7	5.5	143
		4.0	Y	144	31.7	3.0	146.7	4.2	434	36.6	3.2	142.7	4.5	386
SERIES II														
B	I	6.0	None	None	31.2	3.1	146.8	4.6	100	34.4	2.4	145.5	4.9	100
		5.25	B	100	31.3	3.2	147.2	4.5	183	32.8	2.2	146.9	5.0	143
		5.25	Y	100	31.8	3.2	146.1	4.9	488	35.5	2.4	145.1	4.2	357
B	IS	6.0	None	None	--------	--------	--------	--------	--------	35.3	2.9	145.5	4.2	100
		5.25	B	100	--------	--------	--------	--------	--------	34.2	2.0	146.3	4.2	107
		5.25	Y	100	--------	--------	--------	--------	--------	36.2	2.5	145.7	4.2	214
E	I	6.0	None	None	31.5	2.9	147.4	5.4	100	34.5	2.6	145.5	5.1	100
		5.25	B	100	30.6	2.8	146.6	5.1	173	34.8	2.5	145.5	4.4	129
		5.25	Y	100	32.1	3.0	146.7	4.9	334	36.4	3.1	144.5	4.5	286
E	IS	6.0	None	None	--------	--------	--------	--------	--------	35.0	2.8	143.5	5.8	100
		5.25	B	100	--------	--------	--------	--------	--------	35.2	3.1	143.3	5.5	129
		5.25	Y	100	--------	--------	--------	--------	--------	37.1	3.0	144.1	4.4	314

[1] Proportions for mixes without fly ash were 94–170–350.
[2] Relative amount of air-entraining admixture used; amount in concrete without fly ash considered as 100 percent.

cretes prepared with the portland cements and those prepared with the portland blast-furnace slag cements.

The amount of air-entraining admixture required to obtain air contents of 4 to 7 percent was greater for all mixes containing fly ash replacement than for the corresponding mixes without fly ash. Where fly ash B was used, from 4 to 102 percent more air-entraining admixture was needed; and for fly ash Y the increase was from 139 to 517 percent. The relative amounts varied according to the type and source of the cement, the size of the coarse aggregate, and the carbon content of the fly ash. For the mixes without fly ash, more air-entraining agent was required for the concretes prepared with the slag cement than for those prepared with the portland cement.

Mixing, Fabricating, and Curing of Specimens

All mixing was done in an open-pan-type mixer in accordance with usual laboratory procedures. The fly ash was added to the mix with the cement. All tests on the plastic and hardened concretes were made in accordance with the applicable ASTM method. The specimens prepared for strength tests were 6- by 12-inch cylinders and 6- by 6- by 21-inch beams, which were tested at ages of 7, 28, and 365 days. All specimens were stored in moist air until tested.

Freezing and thawing tests were made on 3- by 4- by 16-inch beams in accordance with the ASTM Method C 292 for slow freezing and thawing in water. Freezing and thawing was continued for 250 cycles or until the specimens showed an average loss in N^2 of 40 percent.

Outdoor exposure tests were made on 16- by 24- by 4-inch slabs. A dam was cast around the top perimeter of each specimen and, when freezing and thawing was expected, the top surface was covered with ¼ to ½ inch of water. Each morning after the water had frozen, flake calcium chloride was spread over the ice at a rate of 2.4 pounds per square yard of surface. After the ice had melted, the calcium chloride solution was washed off and fresh water was left on the surface of each slab. The slabs were examined periodically and rated for amount and depth of scaling of the exposed surface. They were subjected to a total of 40 applications of calcium chloride.

Strength Tests

The results of the compressive and flexural strength tests on concrete with and without fly ash replacement are given in table 3. This table also gives the compressive strength ratio of the concrete prepared with fly ash, expressed as a percentage of the strength of the corresponding concrete without fly ash. This was referred to in the previous report as relative strength.

Average values for the compressive strength ratios of the concrete for Series I at various ages are shown in the left half of figure 1. A direct comparison is shown between the concretes prepared with fly ash and the portland cement and the slag cement from the same source. The upper diagrams show the compressive strength ratios of the concretes prepared with the two types of cement from source B and containing the two fly ashes as replacements for one-third of the cement. These diagrams show that at 7 and 28 days the strength ratios of the slag cement concretes were slightly higher than the strength ratios of the corresponding portland cement concretes, regardless of whether fly ash B or fly ash Y was used as a replacement. At an age of 1 year, the strength ratios of the portland cement concretes were higher than the strength ratios of the slag cement concretes for both fly ashes B and Y. Values given in table 3 show that at 28 days and at 1 year, the actual compressive strengths of the concretes prepared with the slag cement from source B, with and without fly ash, were higher than the actual strengths of the corresponding concretes prepared with portland cement.

The lower diagrams in the left half of figure 1 show the compressive strength ratios of the concretes prepared with the two types of cement from source E, with the two fly ashes as replacements for one-third of the cement. At all ages the strength ratios of the concretes prepared with the portland cement were greater than the strength ratios of the slag cement concretes. At 7 and 28 days there was little difference between the strength ratios of the concrete prepared with the two types of cement, but at 1 year the difference between them was pronounced. Table 3 shows that the actual compressive strengths at all ages were lower for the concrete prepared with the slag cement from source E than for the corresponding portland cement concrete.

Table 3.—Results of strength tests [1]

Cement			Fly ash		Flexural strength			Compressive strength			Strength ratio [2]					
Identification		Amount	Identification	Amount	7 days	28 days	1 year	7 days	28 days	1 year	Flexural strength			Compressive strength		
Source	Type										7 days	28 days	1 year	7 days	28 days	1 year
SERIES I																
		Bag/cu. yd.		*Lb./cu. yd.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*P.s.i.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
B	I	6.0	None	------	585	755	800	3,580	5,340	6,900	100	100	100	100	100	100
		4.0	B	148	420	630	980	2,240	4,050	7,280	72	83	122	63	76	106
		4.0	Y	144	325	550	920	1,730	3,190	6,040	56	73	115	48	60	88
B	IS	6.0	None	------	525	750	935	3,360	6,180	8,250	100	100	100	100	100	100
		4.0	B	148	410	695	920	2,160	4,950	7,590	78	93	98	64	80	92
		4.0	Y	144	345	615	900	1,660	3,850	6,990	66	82	96	49	62	85
E	I	6.0	None	------	685	780	790	4,340	5,410	6,650	100	100	100	100	100	100
		4.0	B	148	555	780	975	3,210	4,980	7,550	81	100	123	74	92	114
		4.0	Y	144	420	640	950	2,380	3,950	6,290	61	82	120	55	73	95
E	IS	6.0	None	------	495	720	935	2,680	4,460	6,450	100	100	100	100	100	100
		4.0	B	148	370	740	920	1,930	3,750	5,670	75	103	98	72	84	88
		4.0	Y	144	290	490	895	1,390	2,980	4,950	59	68	96	52	67	77
SERIES II																
B	I	6.0	None	------	585	755	800	3,580	5,340	6,900	100	100	100	100	100	100
		5.25	B	100	515	750	985	3,350	5,280	8,550	88	99	123	94	99	124
		5.25	Y	100	490	705	955	2,890	4,680	7,680	84	93	119	81	88	111
E	I	6.0	None	------	685	780	790	4,340	5,410	6,650	100	100	100	100	100	100
		5.25	B	100	630	780	895	3,890	5,430	7,740	92	100	113	90	100	116
		5.25	Y	100	590	685	775	3,530	4,920	7,190	86	88	98	81	91	108

[1] Each value is average of three tests.
[2] Based on strength of concrete without fly ash (relative strength in previous report).

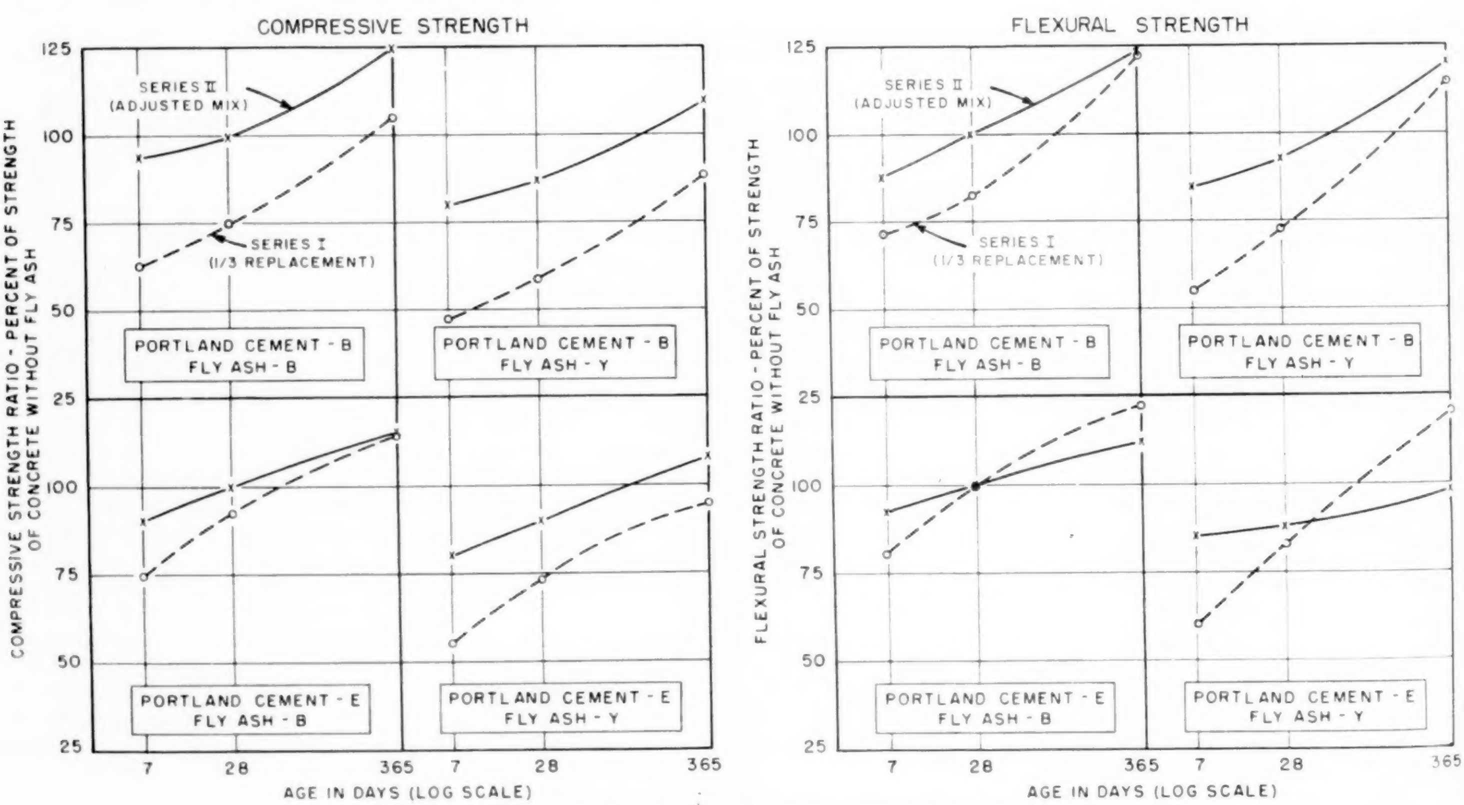

Figure 2.—Effect of adjusted fly ash mix on strength of concrete.

The compressive strength ratios of the concrete prepared with the slag cement and containing one-third fly ash replacement were lower than 100 percent. In the four combinations of cement and fly ash, these ratios increased as the age of the concrete increased. It appears unlikely, however, that these strengths of fly ash concrete would eventually equal the strengths of the corresponding concrete without fly ash. Conversely, at 1 year the compressive strengths of the concretes containing portland cement and fly ash B had exceeded the strengths of the corresponding concretes without fly ash.

The flexural strength ratios of the concretes for Series I are shown in the right half of figure 1. The upper diagrams show the flexural strength ratios of the concretes prepared with the two fly ashes as replacements for one-third of the two types of cement from source B, and the lower diagrams show the flexural strength ratios for concretes prepared with cements from source E.

The same trends are shown for flexural strengths as were shown for compressive strengths: That is, the strength ratios of the concretes prepared with the slag cement from source B were higher at 7 and 28 days and lower at 1 year than the strength ratios of

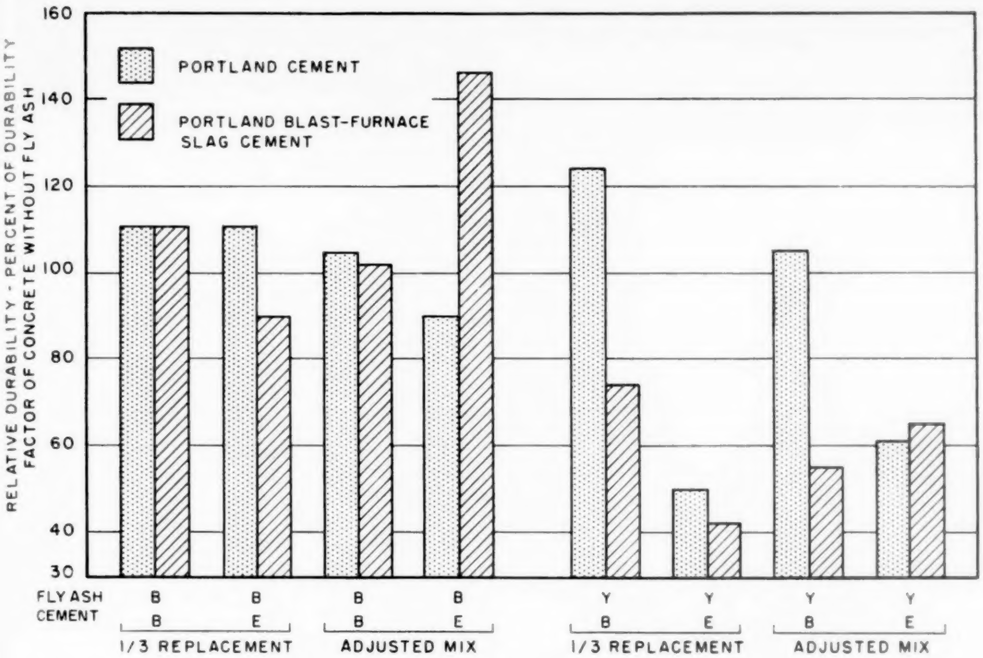

Figure 3.—Effect of replacement of portland or portland blast-furnace slag cement by fly ash on durability of concrete.

corresponding concretes prepared with the portland cement. The strength ratios of the concretes prepared with the slag cement from source E were lower at all ages, except the 28-day test of concrete containing fly ash B. Table 3 shows that at 1 year the actual flexural strengths of the slag cement concretes with one-third fly ash were higher than the actual strengths of the concretes prepared with portland cement without fly ash.

Strength tests using the adjusted mix recommended by the producer of fly ash were made only with the type I portland cement. The results of these tests and the strength ratios of this concrete are given in table 3 as Series II and are shown in figure 2. This figure also shows a comparison between the strength ratios of the concretes for Series II and similar concretes for Series I.

In these tests, the effect on the strength of the concrete of both the source of the cement and of the fly ash is quite marked. As shown in the left half of figure 2, compressive strength ratios were higher at all ages for the adjusted mix of 5.25 bags of cement per cubic yard than for the mix with a cement content of 4.0 bags.

As shown in the right half of figure 2, flexural strength ratios at 7 and 28 days were equal or higher for the adjusted mix, in all cases. At 1 year the adjusted mix for the concretes prepared with cement B with both fly ashes had higher strengths, but when cement E was used the strengths were lower.

The results of these tests support the claim of the fly ash producer that the adjusted mix will give good concrete strengths at early ages. The average compressive strength ratio of the adjusted mixes prepared with fly ash B at 28 days was 100 percent, and for fly ash Y it was approximately 90 percent. Likewise, the flexural strength ratios averaged 100 percent for fly ash B and 90 percent for fly ash Y.

Laboratory Freezing and Thawing Tests

Freezing and thawing tests were made in accordance with ASTM Method C 292 for resistance of concrete specimens to slow freezing and thawing in water. Tests were made using all four cements and both percentage replacements of the two fly ashes. The results of these tests are given in table 4. This table gives the loss in N^2 at 50, 100, 150, 200, and 250 cycles, and the durability factor, calculated on the basis of 250 cycles or a maximum loss in N^2 of 40 percent. In addition, the relative durability of the concrete is given. This is expressed as the ratio of the

Table 4.—Results of laboratory freezing and thawing tests [1]

Cement			Fly ash		Loss in N^2 at cycles shown [2]					Durability factor	Relative durability [3]
Source	Type	Amount	Identification	Amount	50	100	150	200	250		
SERIES I											
		Bag/cu. yd.		*Lb./cu. yd.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*		*Pct.*
		6.0	None		1	11	38	(159)		38	100
B	I	4.0	B	148	0	6	31	(174)		42	111
		4.0	Y	144	1	14	28	(195)		47	124
		6.0	None		0	0	28	(195)		47	100
B	IS	4.0	B	148	0	0	7	32	(215)	52	111
		4.0	Y	144	5	18	(145)			35	74
		6.0	None		0	0	3	11	20	80	100
E	I	4.0	B	148	0	0	0	5	11	89	111
		4.0	Y	144	0	11	33	(166)		40	50
		6.0	None		0	0	9	40	(200)	48	100
E	IS	4.0	B	148	0	0	21	(178)		43	90
		4.0	Y	144	0	(85)				20	42
SERIES II											
		6.0	None		1	11	38	(159)		38	100
B	I	5.25	B	100	0	6	35	(166)		40	105
		5.25	Y	100	0	18	35	(166)		40	105
		6.0	None		0	0	28	(195)		47	100
B	IS	5.25	B	100	0	0	16	40	(200)	48	102
		5.25	Y	100	0	32	(108)			26	55
		6.0	None		0	0	3	11	20	80	100
E	I	5.25	B	100	0	0	1	23	28	72	90
		5.25	Y	100	0	1	12	38	(205)	49	61
		6.0	None		0	0	9	40	(200)	48	100
E	IS	5.25	B	100	0	0	5	17	30	70	146
		5.25	Y	100	0	22	(130)			31	65

[1] Each value is average of three tests.
[2] Figures in parentheses indicate number of cycles at which a loss of 40 percent was reached.
[3] Based on durability of concrete without fly ash.

Table 5.—Results of outdoor scaling test

Cement			Fly ash		Air	Rating[1] after—	
Source	Type	Amount	Identification	Amount		15 cycles	40 cycles
		Bags/cu. yd.		*Lb./cu. yd.*	*Pct.*		
B	I	6.0	None	None	5.3	2½	4½
		5.25	B	100	4.5	3	4½
		5.25	Y	100	4.5	4½	7
E	I	6.0	None	None	4.8	2	4
		5.25	B	100	6.2	2	3
		5.25	Y	100	5.3	5	7½

[1] Rating after freezing and thawing with calcium chloride for indicated number of cycles. A rating of zero represents no scaling; a rating of 10 represents deep scaling over entire surface.

durability factor of the concrete with fly ash replacement to that of the corresponding concrete without fly ash.

The relative durability factors are shown in figure 3. When fly ash B was used as a replacement, the relative durability in all cases was 90 percent or more and in six of eight cases it was over 100 percent. With this fly ash and a cement content of 4.0 or 5.25 bags, more durable concrete was usually obtained than with a 6.0-bag, air-entraining concrete not containing fly ash. When fly ash Y was used, durable concrete was obtained only with portland cement from source B. With this high-carbon fly ash, the concretes prepared with slag cement from source B and both cements from source E showed poor durability.

When all mixes containing fly ash were considered, it was found that those prepared with portland cement had a somewhat greater relative durability (95 percent average) than those prepared with slag cement (86 percent). Comparisons between the fly ash concretes of Series I (4.0 bags of cement) and those of Series II (5.25 bags of cement) showed both to have very nearly the same relative durability. However, the slag cements of Series I had a lower durability factor (79 percent) than those of Series II (92 percent).

These tests indicate that satisfactory durability was obtained for concrete when fly ash B (low-carbon fly ash) was used. This applied to all sources and types of cement used. The tests also indicated that poor durability was usually obtained for concrete when fly ash Y (high-carbon fly ash) was used. Only the concrete prepared with the portland cement from source B gave satisfactory durability with this fly ash.

Outdoor Scaling Tests

Table 5 shows the results of the periodic examinations of the slabs which were exposed to cycles of outdoor freezing and subsequent thawing with calcium chloride. Tests were made on concretes prepared with the portland cements only, and when fly ash was used as a replacement of cement, the amount was that recommended by the producer. The specimens were rated according to the amount and depth of scaling. A rating of zero indicated no scaling and a rating of 10 indicated deep scaling over the entire surface of the specimen.

These tests showed that at 40 cycles the concretes which contained fly ash B had resistance to scaling equal to or slightly better than similar concrete without fly ash. Where fly ash Y was used, however, the resistance was poorer than that of the concrete without fly ash.

Dynamic Weighing of Vehicles

(*Continued from p. 204*)

formance of the scale and the effect of preloading on platform vibrations. Also planned is the design, installation, and testing of at least two types of experimental scales—probably the previously described "broken bridge," and a triangular concrete platform supported by two load cells and a hinge. Continued research is also planned in the development of a beam-supported electronic scale, which utilizes the strain produced by bending as the weight sensor; this will probably use two rectangular aluminum beams as the supporting elements. Corollary to all of this work is further research into the problem of a dependable waterproofing system for the SR–4 strain gage.

All of the test installations will be made in the exit ramp to the north loadometer site on Interstate Route 64, about 50 miles west of Lexington, Ky. Two concrete pits of the proper size, one to receive the commercial scale and the other for the experimental scales, will be built in the right-hand lane of the 24-foot wide ramp pavement. Provisions have been made for a smooth, level approach to the test area. The testing program will include axle-load data collection, overload detection, and diversion of overload vehicles for static weighing.

The Michigan State Highway Department is undertaking a cooperative project with the Bureau of Public Roads, to investigate the overall problem of collecting data on vehicles moving in the traffic stream. These data would include weight, axle spacing, speed, overall length, and other items. It is also proposed to develop a means of transmitting this information to a central location, where it will be automatically analyzed and processed into usable form.

The Michigan and Kentucky projects are intended to complement each other. This joint effort and the efforts of others concerned with the subject should result in solutions to the problems of dynamic weighing, thus providing highway planners with a source of reliable design data and enabling the States to better enforce their load limit regulations.

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